LOST CIRCULATION EXPERIENCE IN GEOTHERMAL WELLS

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ABSTRACT

Lost circulation during drilling and cementing in geothermal wells is a problem common to most geothermal areas. Material and rig time costs due to lost circulation often represent one fourth or more of the total well cost. Assessment of the general drilling and completion practices commonly used for handling lost circulation have been surveyed and evaluated under a study sponsored by Sandia National Laboratories. Results of this study, including interviews with geothermal production companies and with drilling fluid service companies, are reported in the paper.

Lost circulation in geothermal wells is generally very different from lost circulation in petroleum wells. Conventional lost circulation materials and squeeze cementing are not always successful in the cavernous and vugular low-pressure formations encountered in geothermal reservoirs. Special completion methods, such as liner and tieback string, are often used to improve cement placement and setting in lost circulation zones. High wellbore temperatures during geothermal cementing magnify the lost circulation problem. Cement retarders may be needed to prevent premature setting at the higher temperatures, yet too much retarder may lead to an unsuccessful completion, particularly because of the large volume of cement that may be required to seal a lost circulation zone.

Conclusions and recommendations are presented for control of lost circulation during geothermal operations. Recent improvements in lost circulation materials and techniques and potential equipment solutions to the lost circulation problem are discussed. Research needs are also identified.

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SUMMARY

Lost circulation during drilling and completion of geothermal wells can be a severe problem, particularly in naturally fractured and/or vugular formations. Geothermal and petroleum operators, drilling service companies, and independent consultants were interviewed to assess the lost circulation problem in geothermal wells and to determine general practices for preventing lost circulation. This paper documents the results and conclusions from the interviews and presents recommendations on engineering and research needs.

INTRODUCTION

Lost circulation during drilling and cementing in geothermal wells is a problem common to most geothermal areas. Material and rig time costs due to lost circulation often represent one fourth or more of the total well cost. Assessment of the problem and general drilling and completion practices commonly used for handling lost circulation have been surveyed and evaluated under a study sponsored by Sandia Laboratories. Results of this study, including interviews with geothermal production companies and with drilling fluid service companies, are documented in this paper.

Lost circulation in geothermal wells is generally very different from lost circulation in petroleum wells. Conventional lost circulation materials and squeeze cementing are not always successful in the cavernous and vugular low pressure formations encountered in geothermal reservoirs. Special completion methods, such as liner and tieback string, are often used to improve cement placement and setting in lost circulation zones. High wellbore temperatures during geothermal cementing magnify the lost circulation problem. Cement retarders may be needed to prevent premature setting at the higher temperatures, yet too much retarder may lead to an unsuccessful completion, particularly because of the large volume of cement that may be required to seal a lost circulation zone.

To assess current drilling and completion practices for handling lost circulation in geothermal wells, industry representatives were interviewed by direct contact and visits. Four geothermal operators, two petroleum operators, three drilling service companies, and two consulting companies comprise the interview group. The specific objectives of the interviews were the following:

1. Identify the common causes for lost circulation in geothermal wells.

2. Evaluate the general procedures for preventing lost circulation from occurring and the methods used for overcoming lost circulation after it has occurred.

3. Compare findings from the geothermal and petroleum industry and draw on petroleum experience to determine potential solutions for application to the geothermal industry.

4. Identify new approaches and needed research to solve the lost circulation problem in geothermal wells.

Objectives 1 and 2 are addressed in the first section of this paper in discussion of lost circulation experience. In the second section, objective 3 is considered in terms of current drilling and completion concepts. The final section considers objective 4 and presents recommendations for R&D.

LOST CIRCULATION EXPERIENCE

Based on results from the survey of industry experience, geothermal operators are using conventional petroleum methods for fighting lost circulation problems. These range from lost circulation materials (LCM) to gunk squeezes. The survey indicates that these methods may or may not be successful in overcoming lost circulation, depending on particular downhole conditions. At present, no major or new advancements in methods or materials have been put forth to solve geothermal lost circulation problems.

Geothermal Drilling Summary

The following observations and conclusions summarize the experience in handling lost circulation in geothermal wells:

1. In sedimentary formations such as the Imperial Valley, lost circulation is not a severe problem. Use of LCM, low mud weight, solids control, and proper hydraulics for hole cleaning are sufficient for handling lost circulation when it occurs.

2. The worst conditions for lost circulation occur in low pressure fractured and/or vugular formations, such as the Geysers. Geothermal and petroleum operators believe that pressure parting and thermal stress cracking due to drilling contribute to the problem, but to what extent is unknown. In these fractured and vugular formations, LCM is generally tried first, followed by cement plugs, followed by blind drilling as a last resort.

3. Shale swelling and wellbore instability can accompany lost circulation. Low mud weight for lost circulation control may not generate sufficient downhole pressure to stabilize shale

zones. Reduced flow rates above lost circulation intervals cause hole cleaning problems and increased fill on bottom. These problems can lead to stuck pipe. With low mud weights, proper mud chemistry is important for control of shale swelling. If wellbore instability is severe and cannot be controlled, the general practice is to set casing to provide wellbore support before commencing with deeper drilling.

4. Concentric drill pipe has been tried by some operators, but the concerns of persons interviewed is that the extra cost in equipment and rig time does not justify its use. Although concentric drill string may prevent lost circulation of mud during drilling, the problem during cementing of casing remains.

Summary of Cementing and Casing Design

When LCM is not effective, setting of cement plugs is the common practice for sealing lost circulation zones. Numerous plugs are often required in order to completely seal a lost circulation interval. From the survey of industry experience, the following conclusions are offered:

1. Cement plugging of lost circulation zones in geothermal wells is often unsuccessful, particularly on the first attempt. The major reason is downhole temperature which is not known accurately enough for determining needed amounts of retarder. Also, movement of formation water and wellbore fluids can wash away the cement slurry or inhibit the setting reaction.

2. Diesel oil-bentonite-cement gunk squeezes, which are used successfully by the petroleum industry to combat severe lost circulation, are generally not used in geothermal drilling because of environmental reasons associated with the diesel oil component. Furthermore, gunk squeezes are difficult to properly design for geothermal wells since the annulus fluid level above the lost circulation zone is not usually known.

3. Sodium silicate systems are being used by some geothermal operators to control total loss of circulation. The sodium silicate gel is pumped into the lost circulation zone ahead of cement, and forms a barrier to retain the slurry while it sets.

4. When setting casing through a lost circulation interval, a liner and tieback string are often used. The liner can be cemented from above and below to ensure a good cement job. Once the liner is set opposite the lost circulation zone, the tieback string can be cemented through a full-opening port without loss of circulation. The full cemented tieback string has no casing wear from drilling and is undamaged from tripping, fishing, plugging, and other operations.

5. Casing problems can result from poorly cemented lost circulation sections. Eccentric loads and stress concentrations can occur due to unequal cement support around the casing. Exposure to formation fluids, particularly flowing fluids, can cause corrosion, pitting, and wear along with hot spots and thermal strains in the casing.

Geothermal Regions

Geysers In the steam dominated Geyser field, reservoir pressure is low, compared to the higher pressures of the water dominated reservoirs in Utah and Baca. This can magnify the lost circulation problem because of drilling induced pressure parting of the rock formations. Operators are uncertain whether lost circulation in the Geysers is governed principally by pressure parting or by natural fractures and vugs, and to what extent the two mechanisms interact and contribute to the problem.

The present solution for lost circulation control involves cement and sodium silicate. If the loss is partial, then lost circulation additives (usually mica or walnut hulls) and/or straight cement are used. Total loss is controlled with cement preceded by sodium silicate gel. Gunk squeezes are not used because of environmental factors and because of the difficulty in determining mixture ratios for the squeeze. Without annulus fluid levels, the balanced plug method for designing a gunk squeeze cannot be used to calculate proper mixture ratios.

Open hole logs are not generally run in the Geysers. Borehole detection devices such as spinner surveys and borehole televiewers are not generally used. The existing version of borehole televiewer cannot withstand the elevated temperatures, but the U.S. Geological Survey has developed a new model which may be serviceable. Presently, operators cannot specifically identify and accurately locate individual lost circulation zones in open hole. In cased holes, the cement bond log is run, but is not dependable for locating lost cement zones or voids behind pipe.

Concentric drill string has been tried by some operators, but did not perform well and the additional running time caused the system to be uneconomic.

Imperial Valley Although lost circulation is not a major problem in the sedimentary formations of this geothermal region, LCM is sometimes used due to pressure induced lost circulation. In general, conventional muds with thinners for high temperature problems and mud density of 9-10 ppg, and good drilling practices with effective rheology, hydraulics, and solids control to maintain the proper equivalent circulating density, will prevent lost circulation problems from occurring in the Imperial Valley.

In theory, lost circulation material should not be needed in the Imperial Valley, but in practice LCM is helpful, particularly in the very permeable sediments. Lost circulation creates a reduction in annulus pressure which complicates the ability to control lost circulation through mud weight alone. Grain size selection methods for lost circulation material do not always correlate in the Imperial Valley with formation plugging needs. LCM seldom stops lost circulation, but usually reduces it significantly.

With regard to cementing in the Imperial Valley, operators are not aware of lost circulation problems, even though cement weights exceed 9 ppg. Remedial cementing is sometimes necessary because of cement fingering caused by underground water percolation.

Two types of casing problems in the Imperial Valley are noted. One is corrosion associated with underground water percolation which could be due to improper cement sealing resulting from lost circulation during cementing. The other is thermal parting and/or buckling due to temperature changes during operations.

Utah. Most experience with lost circulation has occurred in the Roosevelt lease. Depth to the top of the reservoir at Roosevelt varies across the field between 1200-7500 feet. Lost circulation occurs in the granite which is covered by a mantle of sedimentary formations.

No casing problems such as buckling or thread jump have occurred at Roosevelt, even though 10-20 cycles of on-off production have taken place.

Concentric drill string was considered and was inquired into for drilling lost circulation zones but has not been used. The borehole televiewer has been used in some wells after drilling to inspect fractures, but generally such detection methods and sensing devices for lost circulation evaluation are not used.

In one Roosevelt well, lost circulation was particularly severe. The problem was aggravated in part by the fact that no formation fluids were encountered during drilling of the lost circulation zone and, hence fluid pressure differential was highly overbalanced. The well is presently used for reinjection of fluids produced during tests in nearby production wells. When first used as an injector, the well would not accept all fluid injected and the casing was then perforated opposite the lost circulation zone. No injection problems have occurred since. Initially, after perforating, the well lost injected fluid to the lost circulation zone with no fluid standing in the casing. But after a number of injection periods, the well began holding fluid, indicating that the lost circulation zone became less permeable.

The lost circulation problem in the Roosevelt well started at 1655 feet when the drill pipe dropped two feet. Approximately two weeks were required to drill through the lost circulation zone from 1655-2000 feet. The extra cost in rig time and materials represented a major part of the total well cost. The day-by-day experience through the lost circulation zones in this well is documented in the Appendix and demonstrates the severity of the problem (lost circulation materials used include large amounts of lumped coal, alfalfa cubes, and plastic bags filled with wood and barite).

Baca In the Baca area, lost circulation is a problem in fractured rock of the Bandalera tuff, causing water flows from above in the Caldera fill because of pressure underbalance. The water influx into the wellbore is accompanied by hole caving and sloughing, generating additional drilling problems. If lost circulation results in partial loss of returns, then use of lost circulation material in the drilling mud is normally tried. If the loss is total, then cement spotting and squeezing is used.

LASL Hot Dry Rock Severe lost circulation problems have occurred during drilling of the wells for the Los Alamos Hot Dry Rock project. In these wells, lost circulation in vugular limestone is complicated by swelling shales above the limestone and unexplained casing failures. Present approach for handling the lost circulation is to set casing immediately above and below the thief zone. In one well, concentric drill string was successfully used over a portion of the hole for control of lost circulation.

Of particular interest are the casing failurs (holes and splits in the casing wall) experienced in the EE-2 well after drilling and cementing were completed. Such failures may be related to the lost circulation zones which could lead to poor cementing and improper casing support. Thermal stresses may be induced in the casing where formation fluids contact the pipe in partially cemented zones, and overburden loads may cause buckling of casing in unsupported regions. Also, trapped fluids due to poor mud displacement by cement can result in collapse pressures due to thermal expansion. Another source of potential casing problems in poorly cemented sections is corrosion and pitting due to formation fluid movement along the pipe. If the fluid contains formation fines, then erosion and pipe cutting can also occur. Such a situation may result due to fluid circulation down the wellbore from a water zone to a lost circulation zone. The specific reason or causes for the casing problems in the EE-2 well have not been identified.

A complete description of the lost circulation history in the GT-2 and EE-1 wells is provided in References 1 and 2.

LOST CIRCULATION CONCEPTS FOR GEOTHERMAL DRILLING AND COMPLETIONS

Specific concepts relating to materials, equipment, and methods for control of lost circulation are discussed below.

Causes of Lost Circulation

When lost circulation occurs, it is important that causes be identified in order that proper remedial procedures can be implemented. Lost circulation causes can be grouped into one of the following four categories:

1. Surface Drilling - For surface hole drilling, formations are generally weak and hole diameter is large. Drill solids from the large hole can build up, generating relatively high downhole pressures that may break the formation.

2. Rapid Drilling - High equivalent circulating density can cause pressures that may exceed the closure stress. Fast penetration rates can load the annulus with drill solids, creating rheology and hydraulic problems.

3. Abnormal Pressure - In drilling through high pressure zones, mud weight is normally increased for well control purposes, but lost circulation may result if a low or normally pressured zone is also encountered. General practice is to set casing through the high pressure interval and change back to normal mud weight for deeper drilling. This requires careful casing point selection. Otherwise, both the high pressure interval and the lost circulation zone will be exposed simultaneously in open hole.

4. Fractured Formations - When encountered, the general practice is to add LCM to maintain returns or use a cement squeeze if LCM is unsuccessful. If necessary, the hole should be forced to desired depth, but the lost circulation problem must be solved at each interval before drilling deeper since, otherwise, problems can compound or occur later. Casing should be set as soon as possible and the casing shoe should always be tested. Deeper drilling should not commence unless the casing seat holds pressure.

The first two categories constitute drilling-induced problems related to hole cleaning capability and equivalent circulating densities. The last two categories are formation-induced problems.

Although the four categories represent separate causes of lost circulation, the categories can be interrelated and this is important for evaluating the primary causes of specific problems. For example, categories 1 and 2 can aggravate and magnify categories 3 and 4 and, conversely, categories 3 and 4 can lead to drilling induced problems similar to categories 1 and 2. The latter situation occurred in the Los Alamos wells (see References 1 and 2).

Selection of Lost Circulation Materials

Without knowledge of porosity or fracture geometry, smaller lost circulation materials should be tried first, with progressively larger LCM used if the smaller materials are not successful. However, as is customary, larger materials are generally tried first with the hope of solving the problem quickly, but this can lead to even greater problems. Larger LCM requires special care in mud handling, pumping is more difficult, and shut-downs are often needed for solids control. Approaching the problem with smaller materials first allows better definition of the downhole problem and provides useful technical information for subsequent operations.

For bridging purposes, the concentration of LCM in the mud is important. For example, with walnut hulls, one operator determined that 10 lb/bbl is the maximum concentration needed for effective plugging. Greater concentrations do not increase the bridging capability and do cause solids control problems. If 10 lb/bbl concentration does not plug the lost circulation zone, then a 50 lb/bbl pill should be spotted into the interval.

As a general rule, LCM bridging of fractures requires that the maximum particle size diameter be one-half the fracture width and that 5% by volume of mud solids be bridging size. LCM size gradation is then required for complete control of lost circulation. This is usually built into most LCM because of the grinding process used for manufacture, which provide the full range of coarse, medium, and fine particles.

In addition to bridging and plugging characteristics, the LCM compressive strength at downhole temperatures is a critical parameter for geothermal drilling. After placement, an LCM plug must be designed to withstand wellbore differential pressure across the plug.

Cementing Considerations

A major problem with cement squeezing and plugging of lost circulation zones is determining the temperature at which the slurry reaches bottom so that squeezes can be properly designed with retarder or accelerator. If actual temperature is greater than expected, then the slurry may set in the drill string causing an expensive clean-out. If, on the otherhand, the temperature is less than expected, the set time will be excessive and will probably result in the slurry flowing out the lost circulation zone before it sets. Ideally, the slurry should begin to set as it is pumped into the lost circulation zone, but this is very dependent on downhole temperature.

Cement may not be the optimum fill material if lost circulation is pressure induced. Cementing pressures will not only overexpand previously induced fractures, but may also create new fractures. Light weight fill material that can expand during setting would reduce pressure parting and provide an effective seal after placement. Such a fill material for high temperature application has not been developed.

In geothermal wells, cement squeezes may not set properly because of water movement around the slurry after placement. Light weight cements which generally require longer setting times are particularly susceptible to washing away.

Cement plugs in lost circulation zones may hinder cementing of casing. Wellbore obstructions caused by cement plugs can generate problems when running casing, displacing mud, and circulating cement.

Swelling Shales Together with Lost Circulation

With both lost circulation and swelling shales as in the Los Alamos wells, mud weight has both positive and negative effects. Low mud weight is needed for lost circulation control, but the reduced hydrostatic mud pressure causes shales to swell. This can only be countered with proper mud chemistry that inhibits shale swelling. In shale zones above lost circulation intervals, the lower flow rates imply less carrying capacity and greater hole fill, and together with shale swelling, generate greater tendency for stuck pipe. This explains the stuck pipe problems encountered in the Los Alamos wells.

New Concepts and Alternatives to Cement Squeezes

Bentonite-diesel-cement gunk squeezes are regarded by operators as having high potential for control of total lost circulation, but these systems must be properly designed and implemented to be successful and, furthermore, the diesel component may not be acceptable for environment reasons. With some research, it may be possible to replace the diesel with another constituent that is environmentally acceptable.

An active research program was undertaken by one drilling service company to solve lost circulation in the Geysers[3]. The research involves sodium silicate as a sealing agent. The project was undertaken with the objective of formulating an additive to drilling mud to create a cement-type system, without the need to use cementing equipment and cement placement procedures. Major advantages of such a system are:

1. Material can be stored on location.

2. Material can be added to mud and left in a pit at the surface. When lost returns occurs, accelerator can be added to the mud and the slurry pumped down the hole.

3. The method eliminates rig time waiting for cementing equipment and personnel.

Temperature problems with conventional cement still exist with the new system which is a combination of cement, clay, silicates and other ingredients. The system is basically retarded and must be accelerated for application depending on bottom hole temperature.

The product is designed for temperatures of 250°-350°F, which corresponds to the expected range of operating temperatures in the wellbore. This is cooler than undisturbed geothermal temperatures because of wellbore cooling during drilling and circulation. If the well is static before plugging operations commence, then temperatures will increase.

Thermal set sand consolidation materials are considered to be a viable alternative to cement plugging. Sand coated systems also have potential. Frac gells and special sand carrier fluids used in sand control are not considered good candidates for geothermal applications because of temperature instability. Research and development of high temperature gells should be undertaken.

Equipment Solutions to Lost Circulation

General consensus among petroleum and geothermal operators is that equipment solutions such as concentric drill string and inflatable packers are not viable for controlling lost circulation. Such methods are not economical, represent overkill, and should be tried only as a last resort. The expense of additional rig time in handling the equipment and for crew training is not justified, particularly in view of the risk that the equipment may not solve the problem. Even if the hole can be drilled with concentric drill string, the cementing problem still remains. Inflatable packers (with or without cement as a filler) raises questions about elastomer instability at elevated temperatures. And what if the packer is not properly placed or does not set or seal? Equipment solutions may have application in big holes where lost circulation is magnified, and mud rheology is more difficult to control. As a general practice, operators believe that lost circulation problems, if properly evaluated, can be solved with materials, either LCM and/or cements with additives.

Casing Considerations

When casing is exposed to geothermal formations because of poor cementing induced by lost circulation, thermal stresses may be generated due to cold spots associated with water movement and corrosion may occur due to solution and temperature electrolysis. A bad cement job can lead to eccentric support and high stress points. If water-based fluids are trapped outside casing, burst or collapse can result from pressure buildup when wellbore temperature exceeds the boiling point, as may occur during production.

For improved cementing of casing opposite lost circulation zones, a liner and tieback string can be used with the following benefits:

1. Lost circulation zones can be squeezed with cement from the top of the liner.

2. Good cement job between tieback string and casing is ensured because the interval opposite the liner has previously been cemented, indicating that the lost circulation zone below will not effect the cement placement in the casing-casing annulus. This eliminates voids and/or pockets of water between casing strings.

3. The tieback system provides a new wellhead valve and production casing string that is undamaged from drilling.

Detection and Evaluation Methods

Operators are not certain whether lost circulation in geothermal wells is truly unconventional and whether we really know the fracture geometry in these geothermal locations. Also, what are the temperature effects and to what extent does high temperature magnify the conventional lost circulation problem? Lost circulation in a given location can be solved only when the cause is understood and the governing parameters are identified. This suggests the need for detection and evaluation tools. Although lost circulation zones can be identified with methods such as the spinner survey, fracture orientation and width and porosity size cannot be determined with existing tools.

RECOMMENDATIONS FOR R & D ON LOST CIRCULATION

Six specific research areas have been identified from the industry interviews. These are discussed separately below.

Correlation of Field Experience

The first step in a R & D program on lost circulation should be compilation and correlation of existing industry experience. A detailed survey and evaluation of well data and drilling reports should be undertaken to determine specific downhole conditions leading to lost circulation problems. The success rate of different remedies for different downhole conditions should be identified. It is recommended that the following four lost circulation categories be considered separately:

1. Drilling large holes
2. Rapid drilling
3. Drilling through abnormal pressure zones
4. Drilling through naturally fractured and/or vugular zones.

Full Scale Testing Facility

In order to evaluate lost circulation materials and procedures under field parameters and to understand the effects of downhole conditions, it would be advantageous and economical to perform full scale tests in a laboratory before going to the field. This requires a facility for performing tests under simulated field situations. Such a facility does not presently exist, and, hence, any new developments for control of lost circulation can only be tested in the field. Not only is field site preparation and rig time expensive, but field testing provides only limited information because downhole conditions cannot be varied and downhole measurements are difficult to obtain.

It is recommended that a full scale testing facility be designed and constructed. The apparatus should have capability to independently simulate the following downhole conditions:

1. Full diameter borehole
2. Wellbore circulation flow at variable flow rates

3. Circulating fluids of different types, including cements and polymers

4. LCM at various concentrations

5. Formation rock types

6. Rock permeability, including fractures and vugs

7. Insitu rock stresses and pore pressures

8. Wellbore pressures and equivalent circulating densities

9. Fluid temperatures and formation temperatures.

Small Scale Laboratory Equipment

In addition to full-scale testing under simulated field conditions as discussed in the above section, it would be practical to test plugging capability of LCM in a "dual flow mode" rather than a single flow mode as is done in existing equipment such as the API tester. The API equipment use a slot aligned with the flow direction so that flow stops when the slot is bridged and plugged. This means the slot experiences the full dynamic pressure of the flow, rather than the actual normal pressure as in a wellbore. Under such conditions, plugging characteristics and plug strength as measured in the test may not be representative of field behavior.

To better simulate field flowing conditions, a dual flow tester is recommended where flow through the slot (simulating a fracture or permeability) is independent of flow pass the slot (simulating a wellbore). This requires a flow channel with slots perpendicular to the channel, providing one flow inlet and two flow outlets. Such a device should have capability to provide back pressure on the slot independent of the channel outlet pressure. Formation pressure and wellbore pressure can then be simulated simultaneously. High temperature capability should also be included.

Analytical Formation Plugging Model

An analytical model of lost circulation would be useful for:

1. Evaluation of the various parameters that effect formation plugging and lost circulation, and

2. Design of remedial procedures for specific well conditions.

Many parameters influence lost circulation. Drilling parameters include drilling rate, circulation rate, mud rheology, LCM size and concentration, and wellbore geometry. Formation parameters include pore pressure, overburden stresses, permeability, fracture or vug size, and geothermal temperatures. A mathematical model that incorporates these parameters as variables should be formulated in terms of fluid mechanics principles.

The model should be tested and correlated with field data and sensitivity studies should be performed on the dependent parameters. The sensitivity studies will identify the most important variables.

With an analytical model, design considerations can be evaluated for control of lost circulation under given field conditions. It may be possible to construct charts or nomographs for selection of drilling parameters and lost circulation materials for specific well conditions.

New Cements and Plugging Systems

Research on materials for plugging of geothermal formations should be initiated. The study should consider, not only plugging capability, but also handling, pumping, and placement techniques. The investigation should emphasize methods and materials for plugging fractured and vugular formations.

A recent literature search on lost circulation indicated that more than two-thirds of the references were patents, all of which deal with methods and materials for formation plugging. It is recommended that these patents be reviewed and evaluated. Many of the patents are associated with sand consolidation systems and placement techniques for sand control purposes. Others are related to selective plugging for reservoir injection and secondary recovery purposes. Materials, equipment, and methods developed for these applications may have use for lost circulation.

Logging Tool for Lost Circulation

Size of formation fractures and vugs should be known in order to properly bridge and plug lost circulation zones. A wellbore tool for measurement of fracture/vug size would be useful for design of remedial procedures. It is recommended that development of a logging type tool for this purpose be undertaken.

ACKNOWLEDGEMENT

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APPENDIX

Daily Record of Lost Circulation Experience
in a Well in the Roosevelt Lease - Utah

Days from Start of Lost Circulation	
1	Lost returns at 1655' - 1657', Fractured formation, Mixed pit with 30% LCM, Drilled to 1678, No returns
2	Lost 1400 bbls mud Pumped 300 bbls mud, 35% LCM, Hole filled to 50' Pumped 300 bbls mud, 35% Lost circulation material Pumped 100 bbls mud in drill pipe, 25 bbls mud in annulus, No returns Pumped high water loss pill, No returns Mixed 1 pit mud, 35% LCM, Pumped in hole Mixed and pumped 50 sacks Class B cement, Tagged top of cement
3	Mixed and pumped 50 sacks Class B cement, Tagged cement Mixed and pumped 50 sacks Class B cement, Tagged top of cement at 1647' Dropped 2 tons alfalfa cubes plus 300 bbls of water, No fill in hole Dropped 1-1/2 tons alfalfa cubes plus 200 bbls water, No fill Dropped 200 gallons soaked burlap sacks

Days from Start	
	Dropped 1-1/2 tons alfalfa cubes plus 200 bbls of mud, 35% LCM
4	Bit in hole, No fill Pumped 200 gelled burlap sacks Pumped 3 tons lumped coal (6" - 9" size) Pumped 2 tons alfalfa cubes Hole filled up Drilled bridges to 1650', Lost returns
5	Dropped 180 burlap sacks in hole Dropped 1 ton lumped coal (6" - 9" size) Dropped 2-1/2 tons alfalfa cubes in hole Dropped 2 tons lumped coal in hole
6	Bit drilled bridges to 750', Lost returns Bit to 1650', Hole clear Dropped 7 plastic bags filled with mud (10" OD x 15' long) followed with gelled mud Hole clear to 1658'
7	Dropped 2 tons lumped coal in hole Pumped 1 pit mud, 35% LCM, Drilled bridges 1675' Spot 150 sacks barite plug, No fill Spot 150 sacks barite plug, No fill Pumped 1 pit mud, 35% LCM
8	Dropped 400 plastic bags filled with wood chips and barite in hole, flushed with 400 bbls mud, No fill
10	Flushed 420 gallons diesel oil Flushed 840 gallons diesel oil mixed with 6 gallons DOC #12 Flushed with 200 sacks Class B cement
12	Drilled 12 hours, No returns Drilled 15 hours to 2004', Tried to run logs
14	Ran 9-5/8", 40 ppf casing, Set at 2001' Pumped 200 sacks Class B cement plus silica flour Pumped 600 sacks Class B cement plus silica flour Drilled to 2160', Lost returns Pumped mud with coarse mica flakes, Fibertex, Plug-It, Cotton seed hulls Pumped mud containing High-Seal paper Drilled to 2240', Full returns Carrying 12% LCM in mud
16	Full returns